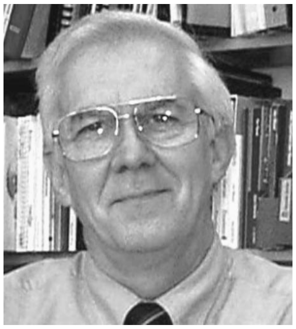

The Journey

This semester I am taking some students on an expedition into the world of geometrical optics, seeking the global optimum. I started the course here at Georgia Tech with 14 travelers, a respectable number these days. But within a few days and for various reasons, including the amount of work the course entailed, those on our trek numbered 7. This is considerably smaller than during the 1980s when the size of our expeditions ran to 20 or more. Still, those who remain evince the same curiosity and interest that their predecessors did. It's just that there are fewer of them!

The course follows my textbook, *Elements of Modern Optical Design*, although I've added a few things since I wrote the text and have incorporated them into the syllabus. For example, I found that the easiest way to compute a chief ray in a spreadsheet is to run an axial ray and then direct a ray at the vertex of the first surface. (I call it a ''first'' ray.) Once the ratio of the ray heights of these two rays at the aperture stop that will add to zero is calculated, the rays can be scaled by that ratio. When the scaled rays are added, the resulting ray is the chief ray for the system. This approach eliminates the need for backward ray tracing, which would be difficult with a spreadsheet.

During the 30 years I have been teaching this course, optical design programs have improved tremendously. But as time and optical design programs have progressed, most of my colleagues and I do not turn our students loose on these programs. Instead, our students are encouraged to develop ray tracing routines for thin lenses and multiple surface traces using the computational applications they are most familiar with (Mathematica, MATLAB, handheld calculators, spreadsheets, etc.). Their work from these applications is entered into a standard form for ease of grading, known as a ''brick wall,'' with no supporting arithmetic required.

The purpose of keeping students away from design programs is to establish an understanding of the concepts of stops, pupils, and windows before introducing them to these powerful tools. This is nearly impossible to achieve if a system prescription is entered into a design program and then analyzed. The result is tantamount to magic. Also, a hand-calculated trace determines the aperture stop for a system, whereas the user of a design program can set almost any surface, even if it isn't the limiting aperture of the axial ray.

Once exact ray tracing is introduced and the Seidel aberrations are described, the design programs are needed to eliminate the tedium of calculation. Although it is possible for students to calculate Seidels, the programs can generate them easily. These programs also provide valuable teaching tools, the ray intercept curves. Once a student can read a set of curves for several field points, he or she has taken the first steps toward understanding lens performance.

Beyond this, the design programs become necessary tools to produce the information needed to understand the effects of parameter variation on aberration correction. Some programs contain features that permit the student to vary one or more parameters and watch the effect of these variations on the ray intercept curves.

Some combination of basic (stops identification) and intermediate (Seidels, intercept curves) analysis provides a student with a solid introduction to optical design. This can be followed by a study of classic designs to assist the student to develop insight into why certain lenses are better than others for a particular application. The next steps, optimization and tolerancing, are not easily taught in an academic setting. This is partly due to the fact that it is difficult for a professor to generate problems with time, budget, and mechanical constraints that approximate a real design. That must wait for training in the real world.

There are a number of things that, to my mind, do not contribute much to the teaching and practice of optical design. One of these is the matrix approach. With the possible exceptions of laser cavities, White cells, and periscopes, where rays reflect or refract from identical elements, matrices are more trouble than they are worth. They don't display the simple progression of rays as a brick wall does.

Another area that does not produce fruitful results these days is the design of lenses using analytical treatments of Seidel coefficients. Before the advent of desktop computers it made sense to seek some advantage in optimization by looking at the solution space for simple systems. But these days, such studies, some of which have been declined as papers for this journal, have been overtaken by technology.

It would seem that with these powerful, easy-to-use tools, an academic course in geometrical optics would be superfluous. There are, after all, courses offered by the companies who sell these programs. But, most optical design program manuals and short courses are not intended to teach optical design principles. They are really aimed at guiding the designer through the use of the program. Usually the manuals include a list of texts that can be used to understand the field. That is what my course does.

In a sense, the education of an optical designer is a three-step process. First, a student must learn the basic concepts and procedures in the field. This can either be done in a formal academic program or by extensive self-study—the equivalent of a strenuous hike. Then some facility with a design program must be acquired. In effect, the designer learns the ropes and picks up some useful tricks. Some of this can be done either in a course such as mine, in a short course given by the program vendor, or on the job. Finally, the now-journeyman graduate finishes his or her training by applying what has been learned to real systems with all the constraints and quirks that arise in an actual application. Here the landscape gets craggy and the method of steepest descent may not find the global optimum. It's quite a road, but the journey can be a satisfying one.

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Editor